

Appendix 6. Diesohol Information

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ATTACHMENT

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ENERGY BALANCES AND CARBON DIOXIDE EMISSION REDUCTIONS FOR VARIOUS SCENARIOS OF PRODUCTION AND USE OF ETHANOL AS TRANSPORT FUEL

A. ENERGY BALANCES

A1. Future Proposed Major Scenario - Ethanol from DEDICATED Lignocellulosic Crops

As stated by Lynd et al. (1), the ratio of energy output to energy input, R, for an ethanol-from-lignocellulosics process may be defined as follows :

$$R = \frac{1 + (3 * E)}{A + T + C + D + P} \dots\dots(1)$$

where : E = cogenerated electrical power;
A = agricultural inputs;
T = raw material transport;
C = chemical inputs in cellulosics to ethanol processing;
D = distribution of ethanol fuel;
P = plant amortisation;

where all energy flows are expressed as fractions of the lower calorific value of ethanol; and,

where the multiplier of E reflects the displacement of thermal energy for conventional coal-fired electrical power generation.

It should be recognised that Equation (1) requires that all processing energy inputs, including ethanol recovery and residues processing, are supplied from combustion of solid residues, principally the mixed cellulose/lignin solid residue. The factor "E" represents surplus cogenerated electrical power from combustion of this solid residue.

Based on the results of work by the United States National Renewable Energy Laboratories (NREL, formerly known as the Solar Energy Research Institute (SERI)), Lynd et al. arrive at a value of 5 for R.

Lynd et al. are silent on the matter of treatment of the liquid process effluents. NREL usually propose anaerobic digestion of the liquid effluent streams and combustion of the methane produced to provide additional electrical power cogeneration. This has the effect of increasing the value of R.

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Lynd et al. and NREL are unaware of the Apace technology for the production of ethanol from lignocellulosics.

If the Apace technology, in particular the Apace simultaneous ethanol recovery/waste treatment process, proves successful the effect will be a significant increase in the value of R from the current value of 5 to a value of at least 7.

The above mentioned increase is achieved because the Apace technology significantly reduces the processing energy input. This in turn leaves an increased amount of cellulose/lignin solid residue available for electrical power cogeneration.

Immediate Future Proposed Major Scenario - Ethanol from Lignocellulosic RESIDUE Materials

In this scenario the agricultural energy input (A) in Equation 1 can be considered as zero. Using the remaining energy input values ascribed by Lynd et al., R then has a value in excess of 12.

With use of the Apace technology R would have a value in excess of 17

Present Situation - Production of Ethanol by the Manildra Group from WASTE Starch Associated with Production of Wheat Products

In the Manildra case the processing energy input, principally that of distillation for ethanol recovery, is currently being switched from combustion of black coal to combustion of natural gas.

Unlike the case with the ethanol-from-lignocellulosics process, there are no solid residues available for combustion from Manildra's ethanol-from-starch plant.

All liquid effluent streams, principally the underflow from the "stripping" distillation column, are currently irrigated onto surrounding land used for intensive pasture production.

The liquid effluent has displaced use of conventional fertilisers and significantly increased the soil carbon content.

the present Manildra operation Equation (1) then becomes

$$R = \frac{1}{A + T + S + C + D + P} \quad \dots\dots(1b)$$

where : S = processing energy input; and,

where all other factors are as defined in Equation (1).

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The Manildra plant is a modern, integrated ethanol-from-starch plant based on well-proven conventional technology. Such plants have a processing energy input of approximately 4.5 MJ/litre of azeotropic ethanol and 5.9 MJ/litre of anhydrous ethanol (ref.2). Based on a lower calorific value of 19.43 MJ/litre for azeotropic ethanol and 21.15 MJ/litre for anhydrous ethanol, and assuming natural gas to steam conversion efficiency of 70%, this converts to a value of 0.33 for factor "S" in Equation (1b) for azeotropic ethanol, and 0.40 for anhydrous ethanol. Manildra have an on-going research and development programme on all stages of the starch-to-ethanol conversion process, and will be supporting work by Apace Research on a low energy requirement simultaneous ethanol recovery/liquid effluent treatment process. Improvements in any stage of the overall starch-to-ethanol conversion process, most particularly in the ethanol recovery and effluent treatment stages, serve to increase the energy balance and reduce greenhouse gas emissions.

A significant proportion of the starch feedstock used by Manildra for ethanol production is waste starch from Manildra's gluten production, or is derived from reject grain. For these starch feedstocks the agricultural energy input, factor "A" in Equation (1b), is zero. Factor "A" will need to be calculated for that proportion of the starch feedstock which is derived from prime wheat. Based on detailed analyses by the United States Department of Agriculture and Department of Energy on the energy input for corn production in the United States (ref. 3), factor "A" for wheat production in Australia is likely to be approximately 0.22. Manildra have a policy of applying best farming practice to wheat production. This will serve to steadily increase the energy balance and reduce greenhouse gas emissions.

If 50% of the starch feedstock used for ethanol production was derived from prime wheat, factor "A" in Equation (1b) would thus have a value of approximately 0.11.

Because the ethanol distillery is annexed to the existing starch/gluten plant the raw material transport input, factor "T", for the waste starch stream is zero. Factor "T" will need to be calculated for that proportion of the starch feedstock which is derived from prime and reject wheat. Transport of Manildra's wheat and starch is predominantly by rail, resulting in a higher energy balance and lower greenhouse emissions compared with road transport. If 55% of the starch feedstock used for ethanol production was from prime and reject wheat, factor "T" in Equation (1b) would have a value of approximately 0.02.

Chemical inputs and ethanol fuel distribution, factors "C" and "D" respectively, in ethanol-from-starch production are approximately the same as for ethanol-from-lignocellulosics production and can be taken as 0.01 (ref.1).

Due to the ethanol distillery being annexed to the existing starch/gluten plant and utilising already existing pretreatment and steam generation plant, the plant amortisation factor "P" for the Manildra distillery is considerably less than that of a new, stand-alone plant. In addition, because there is no solid residue with the Manildra ethanol-from-starch plant there is no solids handling or electrical power cogeneration equipment typical of an ethanol-from-lignocellulosics plant. Accordingly, a value of 0.01 is assumed for factor "P" (ref.1).

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Thus from Equation (1b), R will initially have a value of approximately 2.0 for azeotropic ethanol and approximately 1.8 for anhydrous ethanol.

This compares favourably with existing best practice ethanol-from-corn plants in the United States which have a value for R of 1.87 for anhydrous ethanol. New, leading-edge United States ethanol-from-corn plants have a value for R of 2.21 for anhydrous ethanol (ref.3).

It is interesting to compare the value of R for Manildra's ethanol with that of CSR's azeotropic ethanol produced from molasses at Sarina in Queensland.

Molasses is the residue from the production of crystal sugar for food.

However, in the case of CSR's azeotropic ethanol-from-molasses plant, the processing energy input is supplied from combustion of the sugar cane bagasse.

Surplus bagasse is also used by CSR for electrical power cogeneration.

Equation (1) is thus relevant to this case

Agricultural input (A) can be considered as zero and raw material transport (T) is insignificant.

Chemical inputs into the ethanol-from-molasses process are likewise insignificant, being considerably less than for the ethanol-from-lignocellulosics and ethanol-from-starch processes.

Thus, even if no electrical power cogeneration is assumed (i.e., $E = 0$), and using the values for factors "D" and "P" ascribed by Lynd et al., R has a value of approximately 20 for CSR's azeotropic ethanol.

B. CARBON DIOXIDE BALANCES

As stated by Lynd et al., an indication of the contribution of the various ethanol fuel production scenarios to carbon dioxide accumulation in the atmosphere is the net carbon dioxide produced per unit energy N. This parameter may be estimated from :

$$N = \frac{f}{R} * C \quad \dots(2)$$

where f = the fraction of energy inputs met by fossil fuels;
 C = carbon dioxide produced per unit energy for fossil energy inputs; and,
 R is as defined in Equation (1).

All the energy inputs identified in Equation (1) and (1b) can be satisfied either by fossil fuels (corresponding to f = 1) or by fuels that do not contribute to carbon dioxide accumulation in the atmosphere, such as wood, bagasse or lignin in stationary applications such as boilers and neat ethanol produced efficiently from lignocellulosics for mobile applications (corresponding to f = 0).

The best case scenario is when f = 0, which results in 100% reduction in carbon dioxide emission.

B1. Ethanol from DEDICATED Lignocellulosic Crops

Reference to section A1 and Equation (2) above shows that R = 5 and f = 1 corresponds to a worst case scenario of approximately an 80% reduction in carbon dioxide emission associated with the use of neat ethanol as fuel compared to the use of fossil fuels, assuming equivalent thermal efficiency of use.

With use of the Apace technology and R = 7, the worst case scenario results in approximately an 85% reduction in carbon dioxide emission

The best case scenario is when f = 0, which results in a 100% reduction in carbon dioxide emission.

B2. Ethanol from Lignocellulosic RESIDUE Materials

Reference to section A2 and Equation (2) above shows that R = 12 and f = 1 corresponds to a worst case scenario of approximately a 92% reduction in carbon dioxide emission associated with the use of neat ethanol as fuel compared to the use of fossil fuels.

With use of the Apace technology and R = 17, the worst case scenario results in approximately a 94% reduction in carbon dioxide emission.

Again the best case scenario is when f = 0 which results in a 100% reduction in carbon dioxide emission.

B3. Production of Ethanol by the Manildra Group from WASTE Starch
Derived from Gluten/Starch Plant

In the Manildra ethanol-from-starch plant natural gas is currently replacing black coal for the processing energy input. Chemical input is produced using fossil fuels. Diesohol E15 is replacing diesel as the transport fuel used for ethanol distribution. However, because the energy inputs are dominated by the processing energy input, a value of 1 is assigned to the factor "f" as a worst case scenario. Factor "C" for natural gas is approximately 56mg/KJ (ref.4).

Thus, for Manildra anhydrous ethanol $N = 31 \text{ mgCO}_2/\text{KJ}$, and for Manildra azeotropic ethanol $N = 28 \text{ mgCO}_2/\text{KJ}$. This compares to approximately 80 mgCO_2/KJ for petrol and diesel (refs.1,4,5).

This corresponds to a 61% reduction in net carbon dioxide emission associated with the use of neat Manildra anhydrous ethanol and a 65% reduction with use of neat Manildra azeotropic ethanol compared to the use of petrol or diesel, assuming equivalent thermal efficiency of use. However the thermal efficiency of internal combustion engines increases when operating on neat ethanol and on ethanol blends compared to both neat petrol and diesel fuel, resulting in slightly greater reductions in net carbon dioxide emission.

It is noted that Manildra will be introducing improved ethanol production methods and replacing fossil fuel inputs with renewable fuel inputs as these become available. The latter measure in particular will dramatically increase the effectiveness of Manildra ethanol in reducing net carbon dioxide emission compared with use of diesel fuel and petrol.

Use of neat CSR azeotropic ethanol for which $R = 20$ would, under a worst case scenario of $f = 1$, result in an approximately 95% reduction in carbon dioxide emission compared to the use of petrol or diesel.

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Ethanol Blend Fuel Example: DIESOHOL E15

One litre of Diesohol E 15 is comprised of:

0.845 litres of diesel fuel
0.150 litres of azeotropic ethanol
0.005 litres of chemical emulsifier

The emulsifier is a petrochemical comprised of only the elements carbon, hydrogen and oxygen. Due to its chemical nature and low concentration in Diesohol the emulsifier is assumed to be diesel fuel

Typical lower calorific values for the relevant fuels are:

36.0 MJ/litre for diesel fuel
19.4 MJ/litre for azeotropic ethanol

From Section B above, typical values for net carbon dioxide emission, N, are as set out below. The values for azeotropic ethanol are worst case scenarios based on factor $f = 1$ and no use of the Apace technology.

80 mgCO₂/KJ for diesel fuel
28 mgCO₂/KJ for Manildra azeotropic ethanol
16 mgCO₂/KJ for ethanol from dedicated
lignocellulosic crops
6 mgCO₂/KJ for ethanol from lignocellulosic
residue materials
4 mgCO₂/KJ for CSR azeotropic ethanol from molasses

Thus the net carbon dioxide emission from one litre of neat diesel fuel is approximately 2.88 Kg, compared to 2.53 Kg from one litre of Diesohol E15 made with Manildra azeotropic ethanol. As noted in Section A3 above however, the liquid effluent from Manildra's ethanol production is used to displace conventional fertilisers and to increase soil carbon content. The reduction in carbon dioxide emission per litre of ethanol production associated with these aspects has been estimated by NSW Department Of Agriculture to be approximately 0.18 Kg thus reducing the net carbon dioxide emission from one litre of Diesohol E15 to 2.50 Kg. This corresponds to a 13.2% reduction in net carbon dioxide emission compared to the use of neat diesel fuel.

The reduction in net carbon dioxide emission is 13.2%, 14.2% and 14.6% for Diesohol E15 made with ethanol from dedicated lignocellulosic crops, lignocellulosic residue materials and CSR molasses, respectively

"Real world" field trials of Diesohol E15 in various countries have shown no significant increase in volumetric fuel consumption of vehicles using Diesohol E15 compared to neat diesel fuel. This is due to the increased thermal efficiency of diesel engines when operating on emulsion fuels containing alcohols and/or water. However, if a 5% increase in volumetric fuel consumption is assumed as a worst case scenario then the use of Diesohol E15 produced from Manildra azeotropic ethanol will result in an approximately 9% reduction in net carbon dioxide emission compared to the use of neat diesel fuel. In the case of CSR azeotropic ethanol the reduction is approximately 10.4%

It should be recognised that Diesohol E15 represents a conservative level of ethanol substitution and that higher levels of ethanol substitution are possible. Up to 30% of ethanol by volume (Diesohol E30) can be used in existing diesel engines with minor adaptation.

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